Feeling the heat: Does global warming spell the end for hydropower?

Citation for published version:
Harrison, G 2004, 'Feeling the heat: Does global warming spell the end for hydropower?', *Power engineer*, vol. 18, no. 1, pp. 30-32. https://doi.org/10.1049/pe:20040107

Digital Object Identifier (DOI):
10.1049/pe:20040107

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
Power engineer

Hydropower: Feeling the Heat

The last few years have been difficult ones for the hydropower industry: the report of the World Commission on Dams made uncomfortable reading; opposition from increasingly active and vocal anti-dam groups; hydro re-licensing in several countries has imposed conditions that restrict operational flexibility and public opinion has led some Western companies to pull out of contentious schemes.

Despite this, the hydropower industry is looking to a role in tackling climate change to secure its future prosperity. With no operational carbon emissions, hydro is seen by many as one of the key technologies in achieving a low carbon future. Doing this in increasingly liberalised markets will be challenging given that the massive upfront costs of dam construction tends to disadvantage hydro relative to thermal alternatives (despite the avoidance of fuel costs). However, recent initiatives to promote renewable generation and future developments in carbon taxation and emissions trading will tend to improve the competitive position of hydro.

The threat of climate change looks set to benefit hydropower but, by its very nature, global warming may pose risks. The most recent projections from the Intergovernmental Panel on Climate Change (IPCC) foresee global mean temperatures rising by almost 6°C by the end of the century along with changes in other climate variables ranging from precipitation to cloudiness. Evidently, renewable technologies, like hydropower, that are driven by the climate will experience changes in their resource.

Climate Impacts

Changes in precipitation levels will be accompanied by increased evaporation rates as temperatures rise. The combination of these changes will have profound effects on moisture levels in river basins and consequently on river flows. Temperature rise will also lead to changes in snow storage, as proportionately less precipitation will fall as snow. The indications are that winter river flows will increase, spring thaws will occur earlier and summer low flows will get lower. It is apparent from a wide range of studies that non-linearities in the hydrological system cause river flows to change proportionately more than the driving change in precipitation. In most cases, temperature has a significantly lesser influence although this tends not to be the case in arid basins such as the Nile.

With hydropower potential defined by the river flow at a given site, changes in flow will alter the energy production. Additionally, as schemes are designed for specific river flow distributions, operation will become non-optimal under altered conditions. This occurs because the production capability is dictated by reservoir size (which limits carryover storage for generation during dry spells) and the turbine capacity (which specifies the operational flow range). As might be expected, the availability of storage tends to lower the sensitivity of energy production to climatic influences.

Changes in production will clearly have an effect on station revenue and a relatively greater impact will be seen where variations in output coincide with high-price periods. In any case, reductions in output will raise unit costs, lower return on investment and lessen schemes' attractiveness to investors; in extreme cases, potential schemes would not be pursued.

The massive capital investment required for hydropower installations makes it imperative that project and policy analyses take account of potential climatic effects. The following sections illustrate how this can be achieved by reference to a planned scheme in Sub-Saharan Africa.

Planned Scheme

The 1600 MW Batoka Gorge scheme is planned to dam the Zambezi River between Victoria Falls and Lake Kariba (Figure 1) and produce over 9000 GWh/year. As is standard in most feasibility studies, plans for Batoka used historic river flow data to indicate future conditions. In examining future climatic effects this clearly cannot be relied on, so hydrological models can provide a necessary link between climate and project profitability (as implemented in a software model, Figure 2).

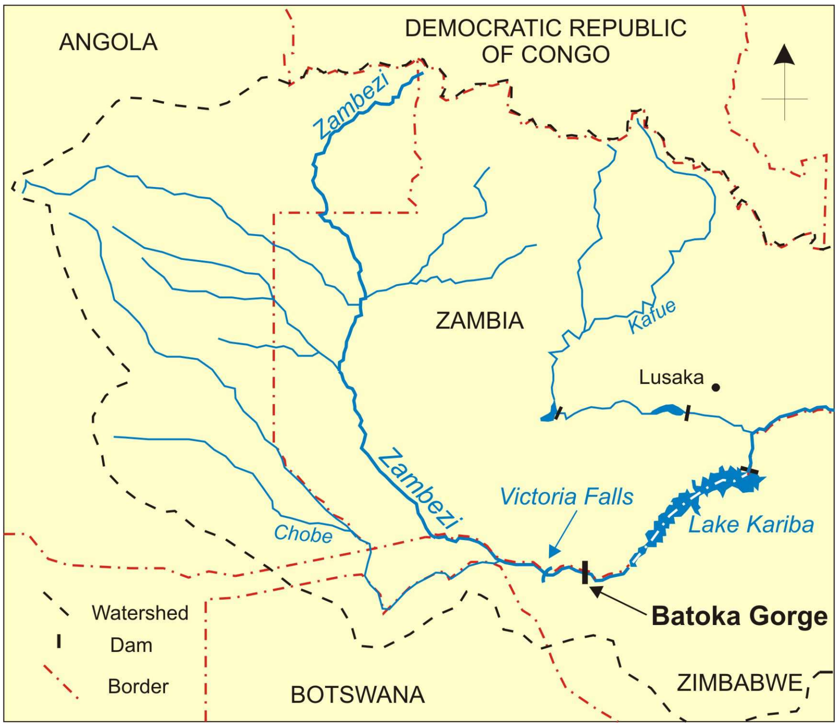

Fig 1: The Zambezi and the Batoka Gorge Scheme

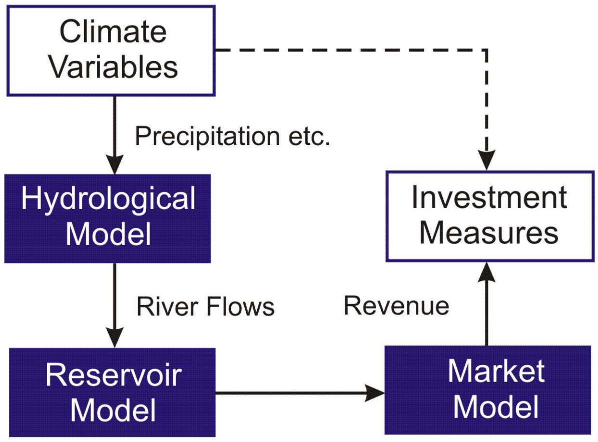

Fig 2: Climate appraisal process

Climate Scenarios

In exploring climatic impacts, the standard approach is to apply scenarios taken from the results of General Circulation Models (GCMs) which are driven by projections of future greenhouse emissions. However, despite similar inputs, it is well known that GCMs tend to give differing projections of future climate. Hence it is common to consider a range of potential future climate scenarios. Scenarios 1 to 3, representing conditions in the 2080s have been used for this purpose. They project temperature rises of around 5°C accompanied by reductions in rainfall of between 2% and 18% (Table 1). They were applied to 30 years of historic regional climate data and allow a comparison between current and future conditions.

Table 1: Summary of climate change and impacts

Changes	**Scenario 1**	**Scenario 2**	**Scenario 3**
Temperature (°C)	+5.0	+5.3	+4.4
Precipitation (%)	–2	–12	–18
River Flows (%)	–10	–28	–36
Production (%)	–6	–16	–21
Project Returns (%)	–6	–16	–21
Climate Risk (%)	+6	+48	+64

Figure 3 shows how the scenarios alter river flows causing reductions in flow of 10 to 35.5%. Although the reservoir at Batoka is relatively small compared to that at Kariba it acts to integrate the river flows and ensure that the impact on electricity production is limited to between 6 and 21% (Figure 4). Of particular note is the fall in dry season (August to December) production where the changes are twice the annual ones. Changes in dry season production have implications for system firm energy levels as, in some cases, mean minimum monthly output reduces by as much as 130 MW (more than the capacity of the existing scheme at Victoria Falls).

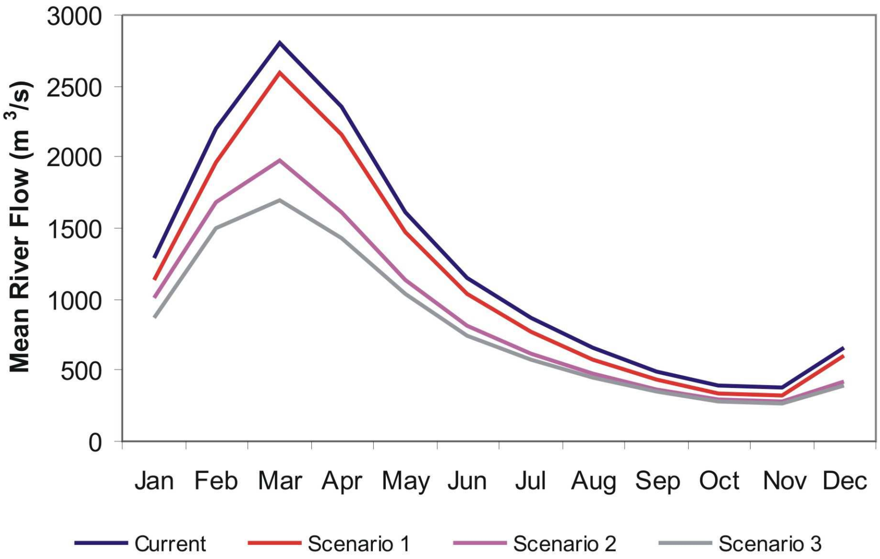

Fig 3: Changes in river flows

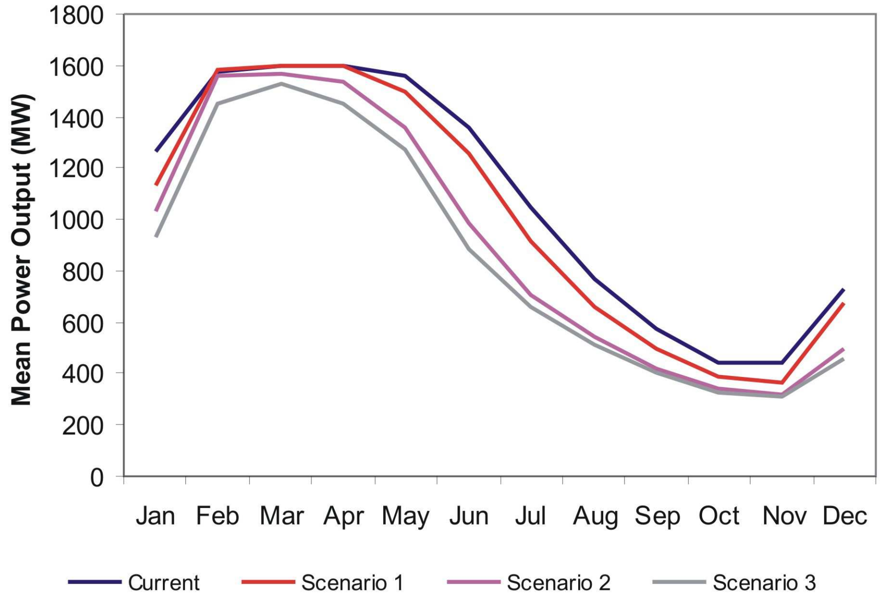

Fig 4: Changes in production

Declining production has a direct and negative impact on the revenue stream. With production paid at a flat rate, percentage changes in revenue follow that for production. With an essentially fixed cost stream, falls in revenue hit the value of the project (Figure 5): the project value is reduced by two-thirds under Scenario 1 and, with Scenarios 2 and 3, actually becomes negative. In any case, it is clear that under the more severe climate scenarios and, in the absence of a revenue stream to reward the production of zero-carbon electricity, the project would become non-viable, financially.

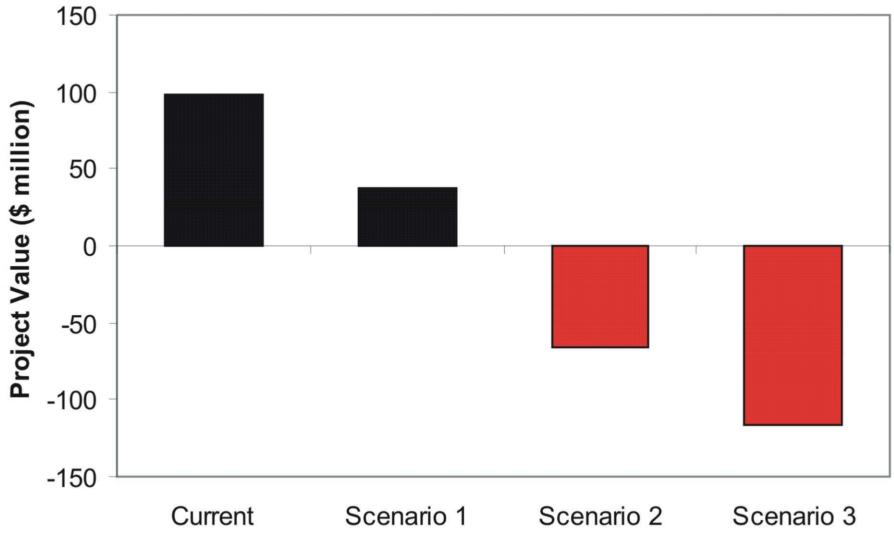

Fig 5: Deterioration in project value

These scenarios are just three from a large number of possible manifestations of future climate and importantly represent a period far beyond that of interest to investors. Additionally they model a step change in climate: climate models project more gradual changes, with nearer time periods experiencing less significant shifts. One way of coping with such difficulties is to use sensitivity studies to identify the tolerance of the scheme to changes in climate. Figure 6 maps changes in project value to combinations of rainfall and temperature changes. The red zone indicates combinations that render the project non-viable and the border clearly highlights the extent of tolerable climate change. It can be seen that as temperature rises, a smaller decrease in rainfall is required to affect scheme viability. The mean changes from the earlier scenarios (S1-S3) are also displayed for comparison.

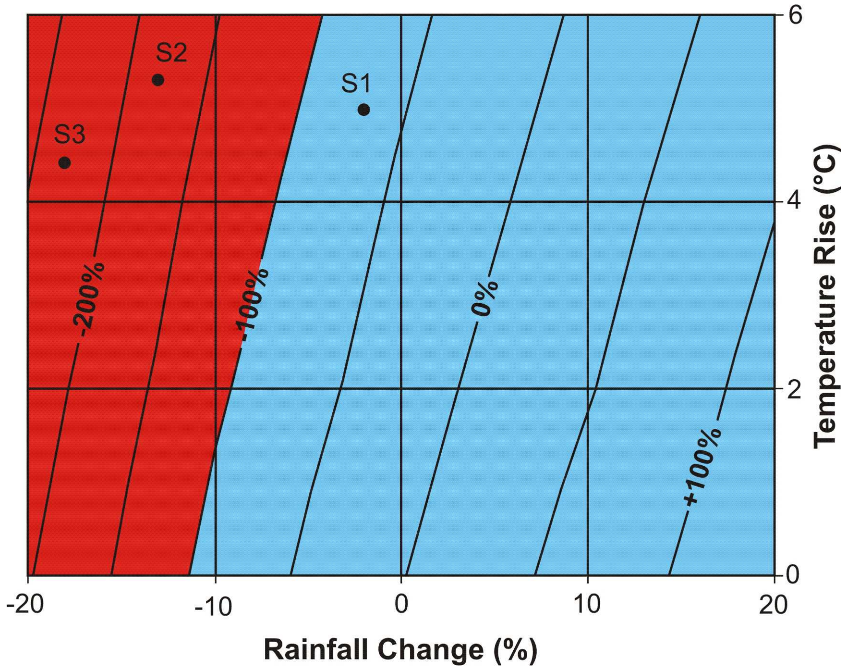

Fig 6: Tolerance of project value to changes in climate

Project Risk

Risk is a critical issue for projects as investors demand greater returns to compensate for higher levels of risk. It has been identified that changes in rainfall alter both the variance and mean level of river flows; a study was conducted to determine whether this would feed through and influence the variance of project returns and alter financial risk.

In analysing this, a Monte-Carlo analysis was carried out using many statistically identical, but temporally different climate series in order to produce distributions of project returns under current and future climate scenarios. With Scenarios 1 to 3 it was found that climate change led to an increased variance of returns and, hence, project risk (Table 1). The increase in risk was related to the severity of rainfall reductions.

The impact on project viability is illustrated in Figure 7 which shows the relationship between project risk and the return expected by investors (as modelled by the Capital Asset Pricing Model). Areas on, or above, the line represent financially viable investments that deliver returns at, or in, excess of that required for the risk level (vice versa for areas below). It is clear from Scenarios 1 to 3 that although expectations for project returns are raised as a result of increasing risk, projected returns are lower.

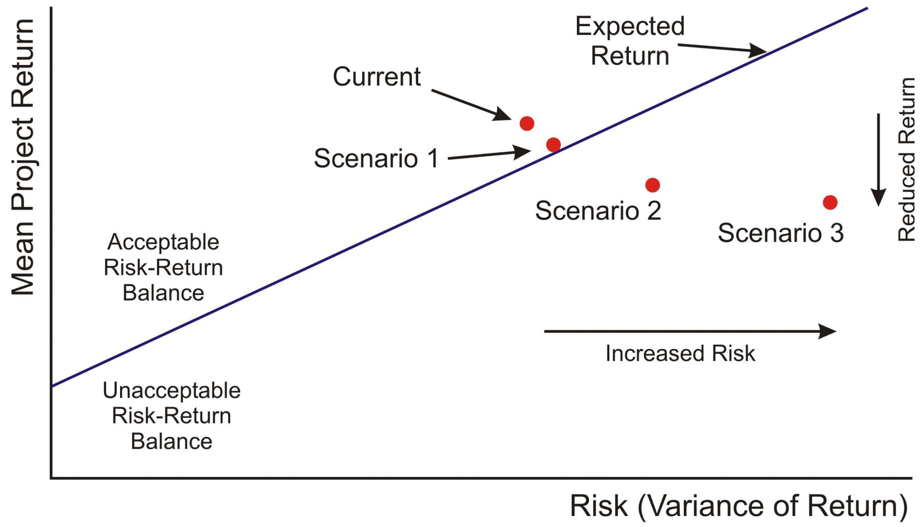

Fig 7: Climate influenced risk and return

Too Hot to Handle?

Taken together, the studies of Batoka imply that hydropower could become less competitive as a result of changes in climate. While the changes are significant and rather alarming, there are several reasons why the threat of climate change might not kill off new hydropower development.

- Impacts will be location-specific – the arid Zambezi appears to be one of the more sensitive rivers.

- Many areas are projected to receive more rainfall, although whether they can take advantage depends on the seasonal timing and intensity.
- Rewards for hydro's zero-carbon production and/or the likely rise in electricity prices resulting from carbon restrictions will enhance the revenue stream, helping to insulate scheme finances from climatic influences

The hydropower industry now recognises climate change as one of it major challenges and needs to examine how climate risk can be transferred or mitigated. In saying that, it will need to act quickly as the effects of climate change are already being seen. In the end, it will be down to investors to make judgements as to whether global warming makes hydro too hot to handle.

Biography

Dr Gareth Harrison is a Lecturer in Energy Systems at the University of Edinburgh. More details of this work can be found at www.see.ed.ac.uk/~gph/climate/.
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